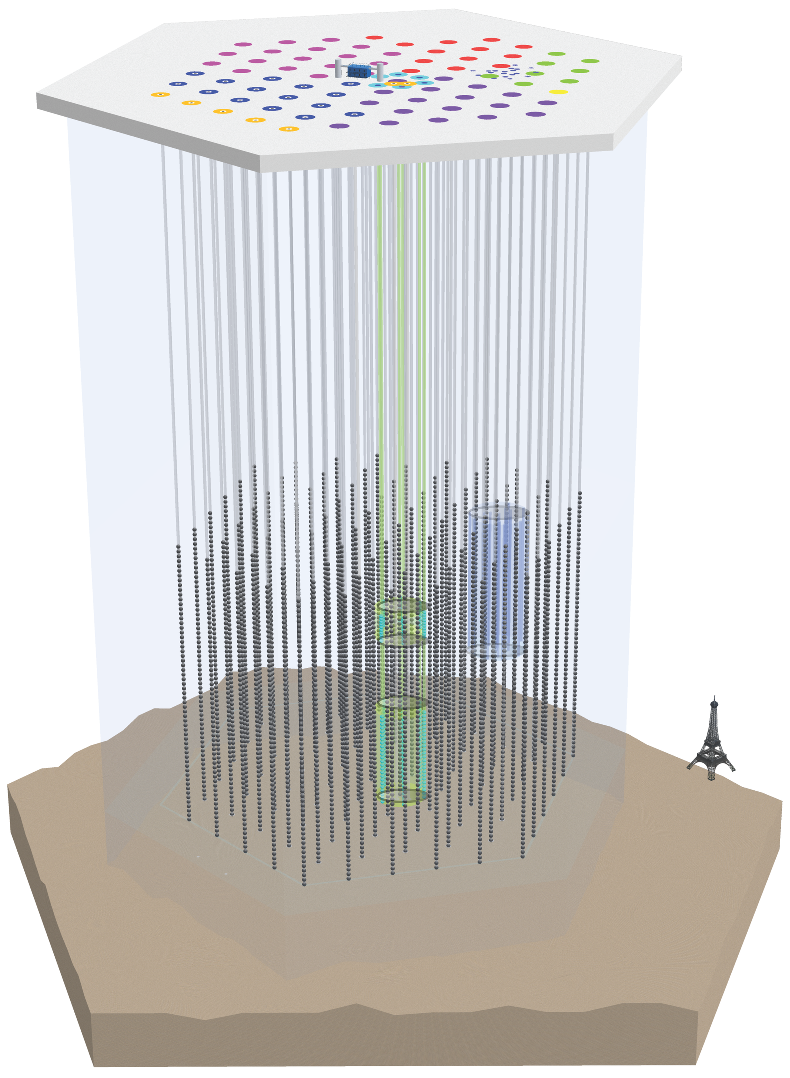


Figure 1: The IceCube detector

Neutrinos To Search For Cosmic-Ray Accelerators

One of the primary goals of IceCube [1] is to detect high-energy neutrinos from the sites of cosmic-ray acceleration. If protons are accelerated to sufficiently high energies in galactic or extragalactic sources, high-energy neutrinos can be produced for example through proton-proton interaction with the ambient gas. As tracers of cosmic-ray acceleration, neutrinos are unique since

- they are only produced in hadronic interactions
- they are not deflected by magnetic fields and can therefore point towards their sources
- they escape from the sites of their production and could, in the future, provide additional information about the nature of their sources.

Neutrinos are detected in IceCube through the light which is produced either by a hadronic cascade at the neutrino-nucleus interaction vertex or by secondary leptons which pass through the detector. Pointing is achieved primarily in the muon neutrino channel, where the tracks of muons emerging from charged-current interactions can be reconstructed through the measurement of photon arrival times within the 3-dimensional grid of IceCube's optical sensors, see Figure 1. A neutrino event is shown in Figure 2.

In contrast to pointing telescopes, IceCube simultaneously monitors all directions in the sky. The best sensitivity to neutrinos is generally achieved for directions in the Northern sky, using the Earth as a filter against all other particles.

During the construction phase, new optical modules have been added to the detector each Antarctic summer. Data has been taken with several configurations of the detector. In this poster, we consider the three detector configurations IceCube 40-strings (2008-2009), 59-strings (2009-2010) and 79-strings (2010-2011).

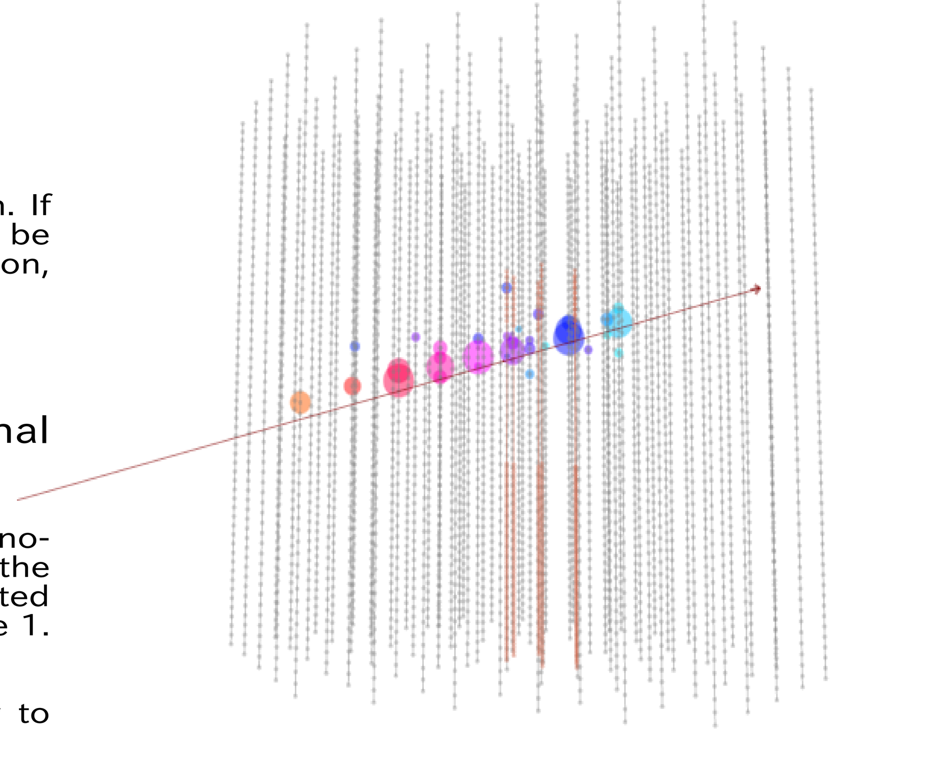


Figure 2 A neutrino event from the IceCube 79-string data

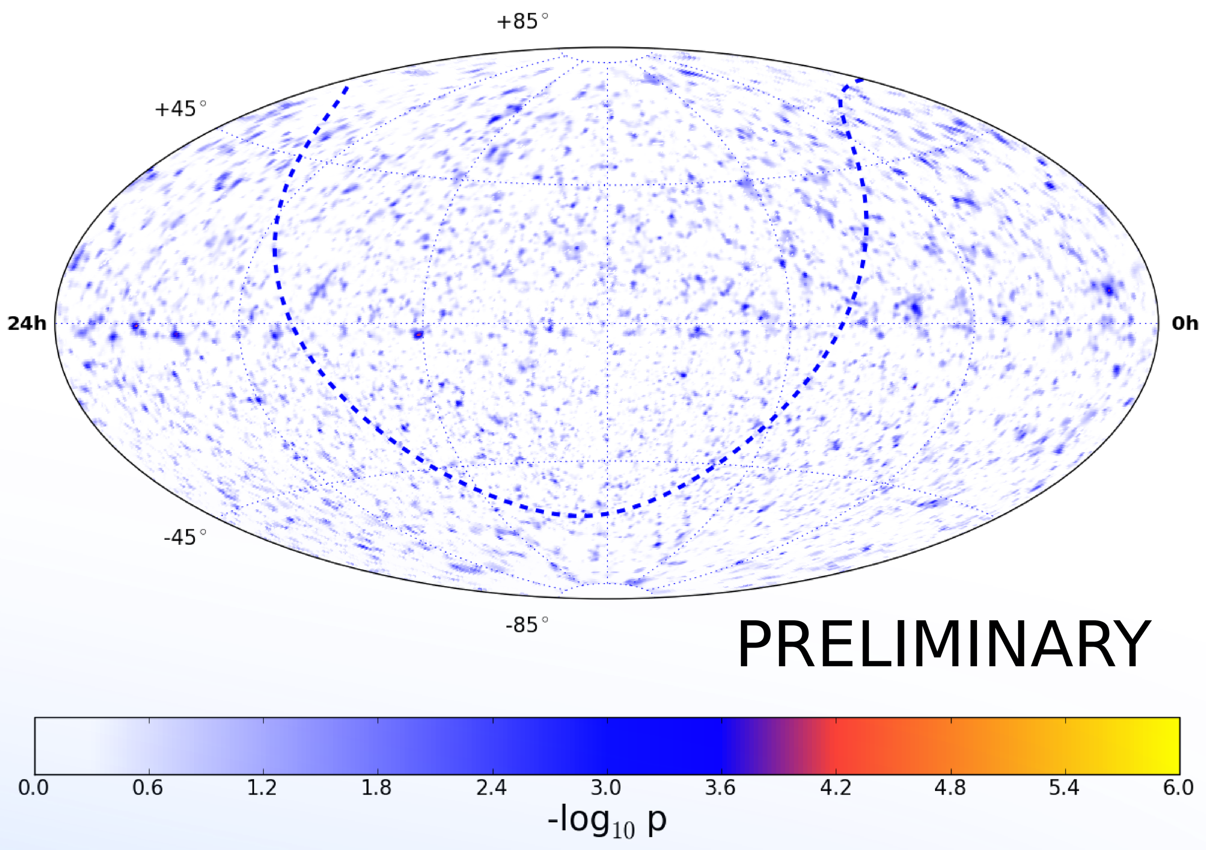


Figure 3: Results from the IceCube 40-strings and 59-strings point source search performed on the combined data from 2008-2009 and 2009-2010 [6]. In the northern sky, the search seeks to find a clustering of neutrino events above the background of atmospheric neutrinos. The background in the southern sky is dominated by high-energy atmospheric muons and bundles of collimated atmospheric muons. The highest local significance is found at (r.a. , dec.) (75.67°, -18.15°) with a local p-value of 10^-4.5. Accounting for the trials incurred by scanning the whole sky ("look-elsewhere-effect"), **the significance of this observation has a p-value of 0.67**. The final p-value is obtained through pseudo-experiments on randomized data. No neutrino source is detected.

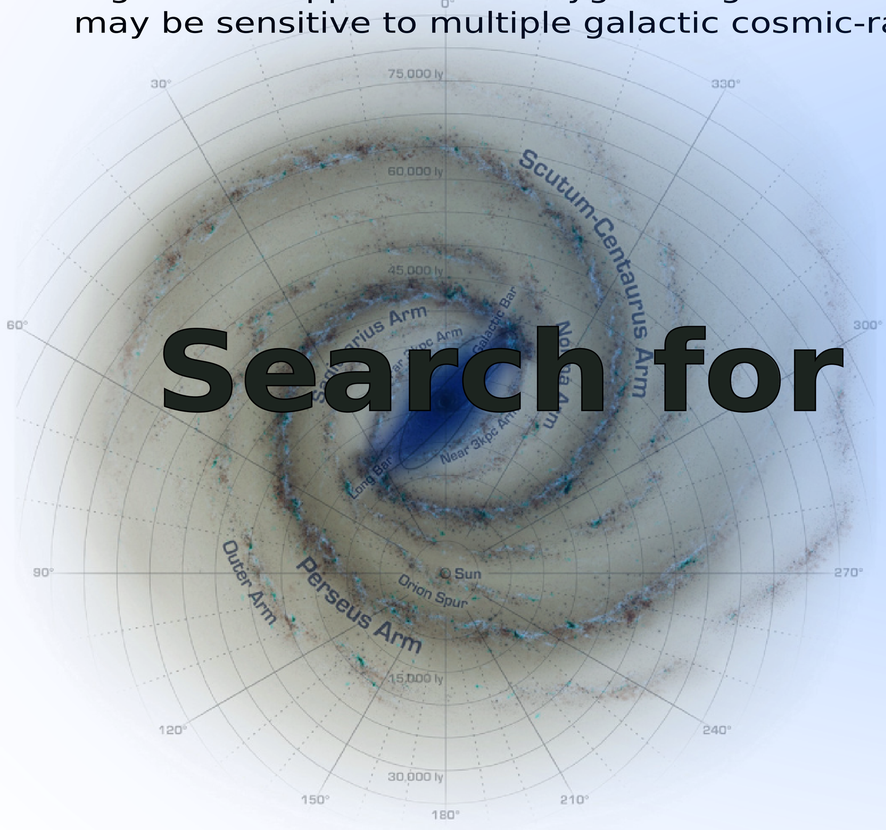
Search Strategies

The IceCube data offers the possibility to search for high-energy neutrino sources in various ways. The most unambiguous identification of a signal would be the detection of a high-energy neutrino point source. Ways to search for this are:

- Search for a spatial **coincidence with astrophysical sources**
- A **scan for neutrino sources** at any position of the sky The result of this test is a sky-map as shown in Figure 3.
- Search for **several weak sources**, each of which may not be strong enough to be detected as an individual point source.

One method to improve the search for multiple weak sources is described in [3] and applied to IceCube data in [3] and [4]. This method searches for correlations between arrival directions of neutrinos within an extended region. It is applied to the Cygnus region of the galactic plane where IceCube may be sensitive to multiple galactic cosmic-ray accelerators.

ICECUBE



Artistic rendering of the Galaxy, from [5]

Neutrino *2012*, Kyoto

Search for High-Energy Neutrino Point Sources with IceCube

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For the IceCube Collaboration

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IceCube 79-Strings

- active from May 2010 to April, 2011
- 6 strings are deployed with a dense spacing.
- almost symmetric detector
- encloses a volume of almost 1 km^3.

Combined with the data from previous years, it will provide the most sensitive search for high energy astrophysical neutrinos to date.

Northern Hemisphere Event Selection

Tracks that reconstruct as up-going would, in principle, represent a pure sample of neutrinos from the northern sky because all other particles are filtered out by the Earth. In practice, this sample is initially highly contaminated by down-going atmospheric muons that been mis-reconstructed as upgoing. We present here the work on a selection of neutrino candidates for the northern hemisphere and a preliminary estimate of its performance for point source searches.

The neutrino candidates are selected by choosing well-reconstructed, up-going events. A typical neutrino candidate event is shown in Figure 2. The selection is performed as a combination of one-dimensional cuts and a series of multivariate cuts based on Boosted Decision Trees [7]. 17 variables in total are selected to train the BDTs with neutrino simulation as signal against atmospheric muon-dominated data to represent the background. The selected variables are sensitive to:

a) track reconstruction quality,
b) energy,
c) containment,
d) rejection of coincident muon events.

Due to the opacity of the Earth at very high neutrino energies and a stronger muon background component at the horizon, we observe that the signal and background distributions of some quality parameters are different at the horizon than for vertically upgoing events, see Figure 5. We account for this by considering two separate declination regions. The final cut is optimzed to obtain the best discovery potential and the estimated muon contamination is less than a few percent.

	IC-59	IC-79
data rate	1.4mHz	1.9mHz
median angular resolution @ 100GeV	1.4°	1.1°
median angular resolution > 100TeV	<0.5°	<0.5°

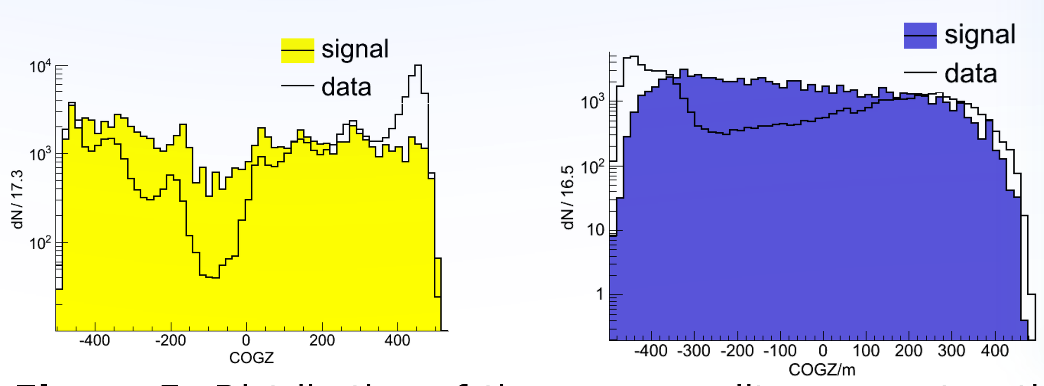

Figure 5: Distribution of the same quality parameter, the depth of the center of gravity of all PMT hits, for a horizontal (left) and a vertical (right) declination region. The assumed signal are neutrinos with an E^-2 spectrum and the data at this level are dominated by atmospheric muons.

Summary

A selection of neutrino candidates from the IceCube 79-string data is presented. With respect to the previous detector configuration, IceCube 79-strings has 15 more strings in the wide spacing that is most useful for neutrino analyses at the considered energies.

- nearly identical detectors at highest energies
- significant improvement in discovery potential
- largest improvements at lower energies:
  - -- significant improvement in effective area
  - -- significantly better angular resolution
- same level of muon contamination.

A further improvement of the discovery potential by a factor 1.5-2.0 will be obtained by the combination with the data from the previous years 2008-2009 and 2009-2010.

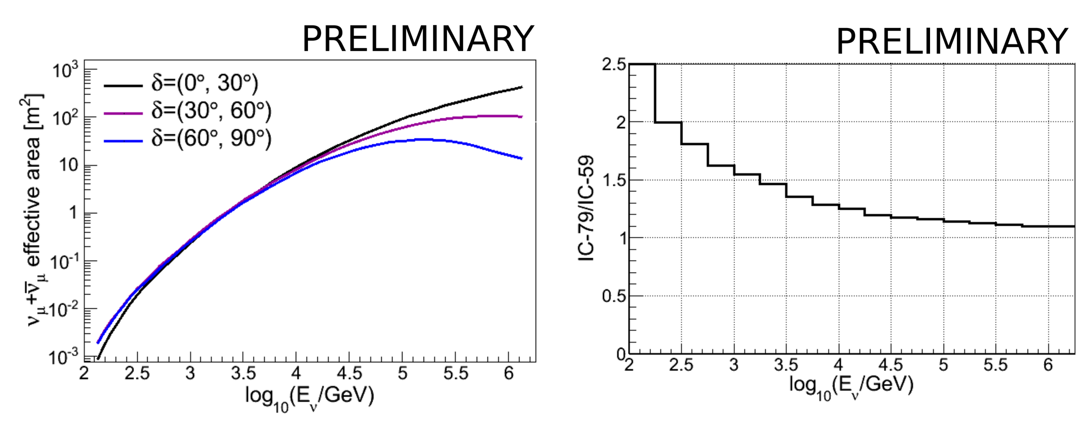

Figure 4: Muon Neutrino Effective Area (left) and Comparison to IceCube 59-strings (right). The improvement at energies up to 10 TeV exceeds the increase in detector size.

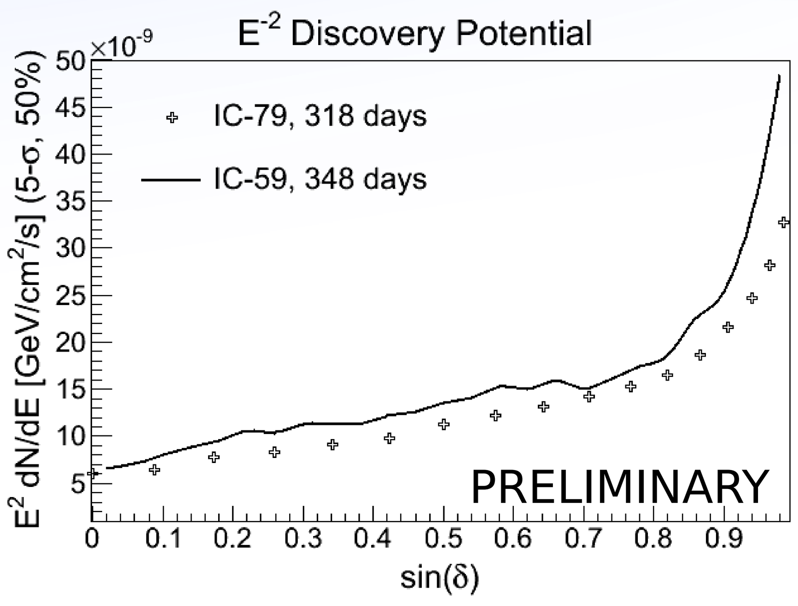

Figure 6: Discovery potential for E^-2 neutrino sources with the IceCube 59-string detector and with the IceCube 79-string event selection presented here. Note that the estimated discovery potential shown includes the effect of the detector configuration livetimes (a longer livetime provides a better flux discovery potential for the same effective area). A further improvement by a factor 1.5-2.0 is ecected from the combination with the previous data samples IceCube 59-strings and IceCube 40-strings.

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